The Extratropical Transition of Tropical Cyclones

Elizabeth A. Ritchie
Department of Electrical and Computer Engineering and
the Center for High Performance Computing
Room 125, EECE Building
Albuquerque, NM 87131-1356
Telephone: (505) 277-8325 fax: (505) 277-8235 email: ritchie@eece.unm.edu

N00014-02-1-0937
N00014-03-1-0831

LONG-TERM GOALS

To improve tropical cyclone structure and intensity prediction through a research program combining high-resolution modeling and detailed observational studies to investigate physical processes by which the structure and intensity of a tropical cyclone are modified.

OBJECTIVES

The objective is to investigate the physical processes that occur as a tropical cyclone interacts with the environment such that intensity and structure changes occur. Specific interactions being studied are with baroclinic environments in the midlatitudes during extratropical transition. During extratropical transition, radical changes to the storm structure occur as vertical wind shear and intruding cold, dry air from the midlatitudes erode the warm core. Re-intensification to a strong midlatitude system is possible. In cases in which forecast models poorly predicted the motion and re-intensification of the storm during these transitional periods, better understanding of these processes should improve motion and intensity forecasts.

APPROACH

Three approaches are being used in this study. First, due to the scarcity of detailed observations in regions where tropical cyclones develop and move, high-resolution, idealized modeling is combined with observations to study the detailed structural changes that occur as a tropical cyclone interacts with the midlatitudes. The degree of physical complexity included in current mesoscale models allows detailed examination of environmental and small-scale impacts on the motion, structure, and intensity of tropical cyclones. However, caution must be taken when applying cause and effect arguments to describe the complex physical interactions that develop in these high-resolution models since they may be a product of the model parameterizations rather than realistic physical processes. Thus, a tiered approach is employed in which understanding of basic processes comes first and is built upon by gradually adding to the complexity of the modeling system, while isolating each physical process in turn. The U.S. Navy's coupled ocean-atmosphere mesoscale prediction system (COAMPS) is the primary model used in these studies into extratropical transition effects on tropical cyclone intensity and structure. Where available, detailed observations such as those available from the ONR-sponsored TCM-92 and TCM-93 field experiments are used to verify processes examined in the model experiments.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **The Extratropical Transition of Tropical Cyclones**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Electrical and Computer Engineering and ,the Center for High Performance Computing Room 125, EECE Building,Albuquerque,,NM,87131**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The extratropical transition of tropical cyclones has been shown to be very sensitive to both the structure of the midlatitude environment and the phasing between the tropical cyclone and midlatitude, upper-level trough. Forecast models have shown significant sensitivity from forecast to forecast depending on how this interaction is handled in the model. Thus, the second approach studies the sensitivity of the interaction between the midlatitude environment and tropical cyclone by varying the both the structure of the midlatitude environment and the phasing between the midlatitude trough and the tropical cyclone. This approach is highly dependent on the versatility of the modeling system employed, where many simple changes to the initial conditions of the model are made to cover a phase space of variability of the relative positions and strengths of the midlatitude environment and tropical cyclone.

The third approach is a new study, which uses a statistical methodology to study the large-scale spatial and temporal patterns associated with extratropical transition. The fields used are the 500-mb geopotential height fields produced twice daily by the Navy's Operational Global Assimilation and Prediction System (NOGAPS). Pattern recognition has been used widely for purposes such as as target identification, and removal of redundancies in hyperspectral imagery. Here, statistically independent patterns are identified in a 10-y set of large-scale fields during ET to determine coherent patterns for intensification, or dissipation of the tropical cyclone remnants during ET. The final purpose of the study is to add value to the NOGAPS forecast.

WORK COMPLETED

Simulations using COAMPS investigated the reintensification patterns that occur as a simulated tropical cyclone interacts with a weak, moderate, and strong upper-level, midlatitude trough. Previous work was extended to include the interaction with an idealized upper-level trough such as might be encountered during extratropical transition. A baroclinic environment was simulated into which upper-level potential vorticity anomalies were inserted and allowed to grow. A tropical cyclone was then inserted into this environment and the structural changes that occurred as the tropical cyclone and upper-level wave interacted were examined. A journal article (Ritchie and Elsberry 2003) from this study was published in the Monthly Weather Review.

Simulations using COAMPS investigated the reintensification patterns that occur as the initial relative locations of a simulated tropical cyclone and an upper-level, midlatitude trough were varied to simulate different phasings between the two weather systems. A series of nine simulations have almost been completed at this stage and diagnostics of the results are being performed and written up.

RESULTS

The extratropical transition of tropical cyclones can be associated with the rapid development of high winds, intense precipitation, and heavy seas, making these transitioned cyclones a significant forecast problem for shipping. Of particular interest is the potential for intensification in some systems when, as part of an interaction with an upper-level trough, re-deepening of the tropical cyclone remnants to a significant midlatitude storm takes place. The sensitivity of the ensuing interaction between the TC and midlatitude upper-level trough is explored in a series of high-resolution simulations using the NAVY's mesoscale model (COAMPS – Hodur 1997). Results from Ritchie and Elsberry (2001), which explored the interaction of a tropical cyclone with a basic background midlatitude environment, are extended by adding a realistic upper-level trough into the simulated midlatitude flow.

(1) In the first series of simulations, sensitivity of the interaction to the strength of the midlatitude upper-level trough is tested by keeping the relative initial positions of the tropical cyclone and upper-level trough constant while varying just the strength of the upper-level trough (Ritchie and Elsberry 2003). Three control simulations, characterized as weak, moderate, and strong, are run in which only an upper-level trough is inserted into the flow without any tropical cyclone, and these are compared to similar runs with a tropical cyclone included in the interaction. When no tropical cyclone is included in the simulation, the minimum surface pressures attained with the weak, moderate, and strong troughs are 1003 mb, 991 mb, and 977 mb, respectively (Figure 1). In all three cases, the low tilts northwestward with height during intensification, and the rainfall pattern and eventual occlusion are representative of classic extratropical cyclone development.

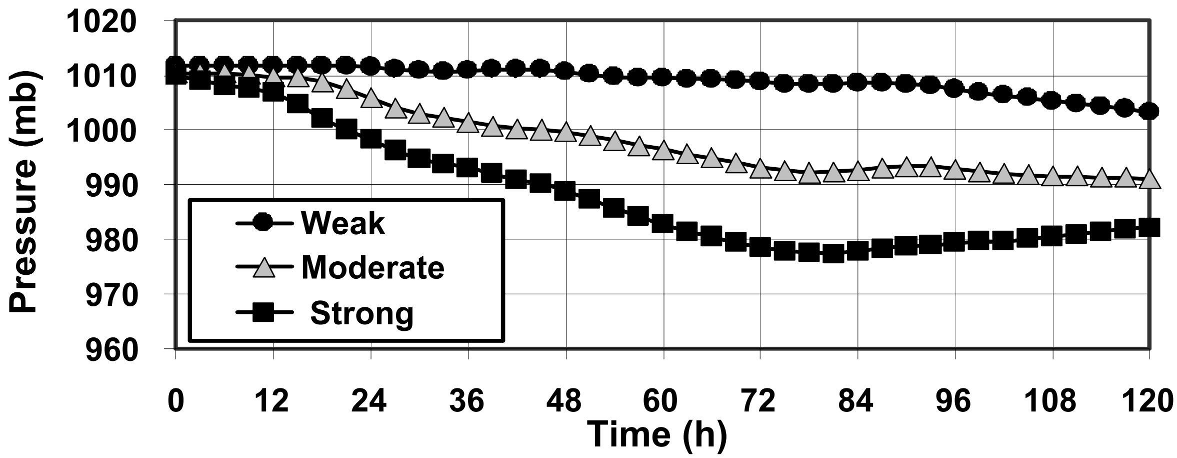

Fig. 1. Time series of the minimum surface pressure for each of the three control simulations of a weak, moderate, and strong developing upper-level trough without a tropical cyclone present.

The interactions of a tropical cyclone with each of the three midlatitude circulation patterns are then compared with the control simulations to illustrate the contributions to the extratropical transition of the tropical cyclone. In the three trough-with-TC cases, the minimum surface pressures were almost identical (967 mb, 965 mb, and 959 mb; Figure 2). Thus, the final intensity of the extratropical cyclone is not only related to the strength of the upper-level trough but must also be related to the basic structure of the midlatitude environment. The proper phasing of the tropical cyclone with the midlatitude trough results in substantial enhancement of upper-level divergence. In addition, higher equivalent potential temperature values in the lower troposphere associated with the tropical cyclone remnants are absorbed in the developing extratropical cyclone. The lifting of this moist air results in precipitation that is greater in both amount and areal extent, which enhances extratropical development when compared with the control cases. Based on these simulations, an important conclusion is that a weak midlatitude trough interacting with tropical cyclone remnants may have as much potential to intensify, as does a strong trough, and may have longer periods of rapid intensification.

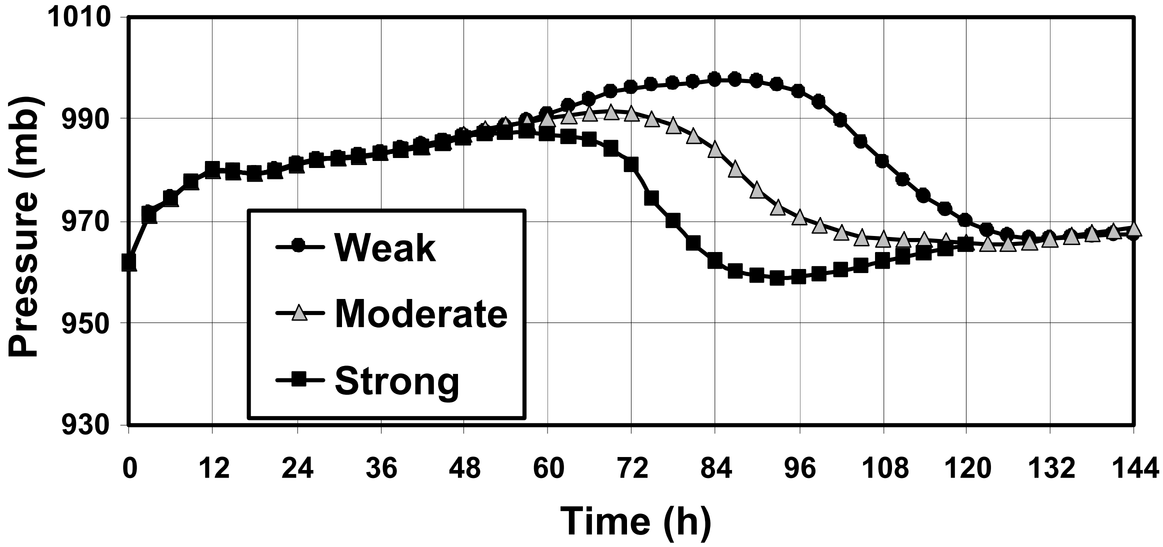

Fig. 2. Time series of minimum surface pressure for each of the three simulations of an interaction between a midlatitude trough and a tropical cyclone.

(2) The second set of simulations using COAMPS investigates the reintensification patterns that occur as the initial relative locations of a simulated tropical cyclone and an upper-level, midlatitude trough are varied to simulate different phasings between the two weather systems. A series of nine simulations have almost been completed at this stage and diagnostics of the results are being performed and written up. Preliminary results indicate a strong sensitivity to the positions where a difference of only a few tens of kilometers may result in slower, and weaker intensification as opposed to deep intensification. Analysis of the results is continuing to determine the source of this sensitivity.

SUMMARY

Significant advances have been made in the understanding of how a tropical cyclone interacts with the surrounding environment. Because interaction with the environment affects a tropical cyclone's intensity and structure, it is important to understand these processes in order to predict intensity change of a tropical cyclone. The intensity changes associated with extratropical transition of a tropical cyclone are particularly difficult to forecast and the knowledge we gain in studying the physical processes associated with the movement of a tropical cyclone to higher latitudes can help to improve forecasts of these phenomena. Because it is very difficult to get high spatial- and temporal-resolution data sets of extratropical transition, the use of carefully constructed high-resolution simulations is one of our best ways of improving our understanding of the physical processes associated with extratropical transition of tropical cyclones. The work described here will be continued in order to advance this knowledge.

New satellite technology has provided an abundance of data sources to forecasters, particularly in the remote tropical oceans where data have been traditionally sparse. These data can be difficult to process in the forecast office where timely forecasts must be provided every few hours. A new project

under this proposal aims to make better use of the wealth of data now available for forecasting of extratropical transition.

REFERENCES

Hodur, R. M., 1997: The Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Mon. Wea. Rev.,* **125,** 1414-1430.

Ritchie, E. A., and R. L. Elsberry, 2001: Simulations of the transformation stage of the extratropical transition of tropical cyclones. *Mon. Wea. Rev.,* **129,** 1462-1480.

Ritchie, E. A., and R. L. Elsberry, 2003: Simulations of the extratropical transition of tropical cyclones: Contributions by the midlatitude upper-level trough to reintensification *Mon. Wea. Rev.,* **131,** 2112-2128.

PUBLICATIONS

Ritchie, E. A., and R. L. Elsberry, 2003: Simulations of the extratropical transition of tropical cyclones: Contributions by the midlatitude upper-level trough to reintensification. *Mon. Wea. Rev.,* 131, 2112-2128.

Ritchie, E. A., J. Simpson, T. Liu, J, Halverson, C. Velden, K. Brueske, and H. Pierce, 2003: Chapter 12. Present day satellite technology for hurricane research: A closer look at formation and intensification. Hurricane! Coping with disaster, R. Simpson, ed. AGU Publications, 249-891.

Ritchie, E. A., 2003: Chapter 12. Some aspects of midlevel vortex interaction in tropical cyclogenesis. Cloud systems, hurricane, and the tropical rainfall measuring mission (TRMM), W-K. Tao and R. Adler, eds. Meteorological Monographs, 29, 165-174.